NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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EFFECT OF REDUCING VALVE OVERLAP ON ENGINE AND COMPOUND-POWER-PLANT PERFORMANCE

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SUMMARY

An experimental investigation of a 62°-valve-overlap, 18-cylinder, air-cooled, radial engine modified with 40°-valve-overlap cams was made to determine the effect of a change in valve overlap on engine performance.

With these data and data on the unmodified 62°-valve-overlap engine as a basis, computations were made to show the effect of change in valve overlap on compound-engine performance.

At rated power, the reduction in valve overlap investigated caused a reduction of 6 percent in net thrust horsepower and a reduction of 2 percent in net specific fuel consumption of the compound engine at the engine exhaust pressure for maximum net power.

INTRODUCTION

The effect of exhaust pressure on engine performance has been investigated on two models of a standard 18-cylinder, air-cooled, radial aircraft engine, one having 40° valve overlap and the other 62° valve overlap and increased cooling-fin area. The results of these investigations are reported in references 1 and 2. The performance of compound power plants using these engines was computed and the results reported in references 3 and 4. These power plants consisted of a turbine and auxiliary supercharger mounted on a common shaft and geared to the engine crankshaft.

The results of the investigation reported in reference 4 showed that the compound power plant using the engine of reference 1 provided more power at a lower net brake specific fuel consumption at cruise conditions (lean fuel-air ratios) than the compound power plant using the engine of reference 2. The better performance of the compound power plant using the engine of reference 1 was attributed to its lower valve overlap (40°) as compared with the engine of reference 2, which had a valve overlap of 62°. The 62°-valve-overlap engine had better cooling characteristics and a higher power rating, however, than the 40°-valve-overlap engine. The better cooling characteristics of the 62°-valve-overlap engine were the result of the redesign of the cylinder fins and the larger valve overlap. In an attempt to combine the best features of both engines, the cams from the 40°-valve-overlap engine were installed in the 62°-valve-overlap engine.

The results of an experimental investigation of the performance of the 62°-valve-overlap engine fitted with 40°-valve-overlap cams are reported herein. Curves that show the effect of engine exhaust pressure on engine power, charge-air flow, volumetric efficiency, and exhaust-gas temperature are included. Curves for the 40°- and 62°-valve-overlap engines are also presented to compare the performance of the three engines and to compare the calculated performance of the compound power plants.

APPARATUS

This investigation was conducted using the R-2800 (C series) 18-cylinder air-cooled radial engine of reference 2 (designated engine 2) equipped with the 40°-valve-overlap cams from the R-2800 (A series) engine of reference 1 (designated engine 1). This modified engine is designated engine 3. Except for the installation of the 40°-valve-overlap cams this setup was exactly the same as that reported in reference 2.

Some of the pertinent specifications for the three engines discussed herein are:

	Engine 1 (A series) (reference 1)	Engine 2 (C series) (reference 2)	Engine 3 (modified C series)
Compression ratio	6.65	6.75	6.75
Blower gear ratio	7.6:1	7.29:1	7.29:1
Impeller diameter, in.	11	11.5	11.5
Propeller reduction-gear ratio	0.50:1	0.45:1	0.45:1
Spark advance, deg B.T.C.	25	20	20
Valve overlap, deg	40	62	40
Valve timing, deg			
Intake opens, B.T.C.	20	36	20
Intake closes, A.B.C.	76	60	76
Exhaust opens, B.B.C.	76	70	76
Exhaust closes, A.T.C.	20	26	20

METHODS

Procedure

For all the conditions of the investigation of the 62°-valve-overlap engine modified with 40°-valve-overlap cams (engine 3), the prime variable was engine exhaust pressure. At each set of engine operating conditions, the exhaust pressure was varied from about 8 inches of mercury absolute to about 20 inches of mercury above inlet-manifold pressure. A list of operating conditions is presented in the following table:

Fuel-air ratio / Engine speed (rpm)	0.063	0.069	0.085	0.100
	Inlet-manifold pressure (in. Hg absolute)			
1600	40	30, 34, 40, 45	40	--------------
1800	40	40	40	40
2000	40	40	40	40
2200	40	40	25, 30, 40, 50	40
2400	40	40	40	40
2600	-----	40	40	30, 40, 45, 50
2800	-----	--------------	40	--------------

Comparison of Power Plants

The three engines discussed herein are compared with each other on a basis of the performance of the engine alone and of the performance of compound power plants using these engines. The engine data for engine 3 (modified engine) are compared with the engine data from references 1 and 2 (engines 1 and 2, respectively).

The compound power plants using these three engines were compared on a net-thrust-horsepower basis in order to include the effects of cooling drag and other factors affecting power-plant performance. The net thrust horsepower includes the engine propeller thrust horsepower (including the power of the turbine), the exhaust jet thrust, the cooling-air drag (or thrust), and the drag of picking up the charge air. Thus:

$$nthp = \eta_p \left[ehp + \eta_g\,(thp - ashp)\right] + jhp - chp$$

where

ashp auxiliary-stage supercharger horsepower, power required to compress charge air from altitude temperature and pressure to carburetor top-deck pressure with duct loss allowance using an efficiency of 80 percent

chp cooling-air drag horsepower based on momentum change of cooling air across engine cowl and assuming average cylinder-head temperature of 450° F

ehp reciprocating-engine horsepower including power of engine-stage supercharger

jhp exhaust jet thrust horsepower including charge-air pickup horsepower

nthp net thrust horsepower

thp turbine horsepower, power obtained from expanding engine exhaust gas from engine exhaust pressure and temperature to altitude pressure through turbine with adiabatic efficiency of 80 percent

η_g gear efficiency, assumed to be 95 percent

η_p propeller efficiency, assumed to be 85 percent

No drag powers associated with intercooler and oil-cooler cooling-air flows are included in the net power because calculations showed them to be negligible. The net thrust specific fuel consumption was calculated by dividing the fuel flow by the net thrust horsepower.

RESULTS AND DISCUSSION

Basic Data for Engine 3 (Modified Engine)

The experimental data and computations are presented in a manner similar to that of references 1 and 2.

The effect of varying the ratio of engine exhaust pressure to inlet-manifold pressure p_e/p_m on brake horsepower, charge-air flow, volumetric efficiency, ratio of indicated mean effective pressure to inlet-manifold pressure ϕ, mixture temperature minus carburetor-air temperature $T_m - T_c$, and exhaust-gas temperature for modified engine 3 is shown in figures 1 to 6, respectively. The variation of the ratio of inlet-manifold pressure to full-open throttle carburetor-inlet pressure p_m/p_c with engine speed is shown in figure 7 for a carburetor-air temperature of 550° R.

References 1 and 2 showed that ϕ and volumetric efficiency when plotted against p_e/p_m are independent of inlet-manifold pressure. Therefore, most of the investigation conducted on engine 3 was at one inlet-manifold pressure. As shown in figures 3 and 4, this correlation was substantiated by a small amount of data obtained at other inlet-manifold pressures.

Comparison of Basic Data for Three Engines

Brake horsepower. - Comparison curves showing the effect of p_e/p_m and engine speed on brake horsepower for the three engines at an inlet-manifold pressure of 40 inches of mercury absolute and a fuel-air ratio of 0.085 are presented in figure 8. Engine 3 provides slightly less power than engine 1 over the entire range of p_e/p_m regardless of the engine speed for the condition shown. Engine 3 also provides less power than engine 2 at the lower values of p_e/p_m but provides more power than engine 2 above values of p_e/p_m of about 1.1. As the engine speed is increased from 1600 to 2400 rpm, the differences in engine power between engines 3 and 2 at the low values of p_e/p_m decrease but the differences at the high values of p_e/p_m increase. For other inlet-manifold pressures and fuel-air ratios, the trends of power with p_e/p_m are the same as shown in figure 8.

Charge-air flow and volumetric efficiency. - The variation of charge-air flow and volumetric efficiency with p_e/p_m and engine speed for the three engines is shown in figures 9 and 10, respectively. The curves in these two figures follow the same trends as the brake-horsepower curves of figure 8. The unusually large increase in charge-air flow with decreasing p_e/p_m at low speeds and below a value of p_e/p_m of 0.5 for engine 1 did not occur with engine 3 in spite of the fact that both engines have the same valve overlap.

Indicated power. - The dimensionless quantity ϕ (ratio of engine indicated mean effective pressure to engine inlet-manifold pressure) is used as a measure of indicated power for any given engine speed and inlet-manifold temperature (reference 5). The variation of ϕ with p_e/p_m and engine speed is shown in figure 11. 668
The curves in this figure indicate the same trends as the curves of brake horsepower in figure 8.

Exhaust-gas temperature. - The effect of p_e/p_m and engine speed on exhaust-gas temperature for the three engines at an inlet-manifold pressure of 40 inches of mercury absolute and a fuel-air ratio of 0.085 is shown in figure 12. The exhaust-gas temperature for engine 3 averages about 100° F lower than that for engine 2 and 50° F higher than that for engine 1 for the entire range of p_e/p_m at an engine speed of 2400 rpm. At lower engine speeds, the exhaust-gas temperatures of the three engines maintain the same relative positions as at the engine speed of 2400 rpm except at high values of p_e/p_m where the temperatures of engines 1 and 3 coincide.

Comparison of Compound-Power-Plant

Performance of Three Engines

The calculated performance of compound power plants using the three engines is shown in figure 13 where the net thrust horsepower and the net thrust specific fuel consumption are plotted against p_e/p_m for a flight velocity of 400 miles per hour and an altitude of 30,000 feet. Figure 13(a) presents the performance of the three power plants at an engine speed of 2200 rpm, a fuel-air ratio of 0.063, and an inlet-manifold pressure of 40 inches of mercury absolute, approximately cruise conditions. At this power level, engine 1 gives a maximum value of 1468 thrust horsepower at a net thrust specific fuel consumption of 0.392; engine 2 gives a maximum value of 1420 thrust horsepower at a net thrust specific fuel consumption of 0.425; and engine 3 gives a maximum value of 1330 thrust horsepower at a net thrust specific fuel consumption of 0.408.

Based on these values for the cruise condition, the compound power plant using engine 3 gives about 9 percent less thrust horsepower at about 4 percent higher net thrust specific fuel consumption than that using engine 1 and about 6 percent less net thrust horsepower at about 4 percent lower net thrust specific fuel consumption than the compound power plant using engine 2.

At approximately rated power (engine speed, 2600 rpm; fuel-air ratio, 0.085; and inlet-manifold pressure, 50 in. Hg absolute, fig. 13(b)), the cruise-power trends of figure 13(a) are considerably changed. As shown in figure 13(b), the compound power plant using engine 3 gives about 2 percent more net thrust horsepower at about 5 percent lower net thrust specific fuel consumption than that using engine 1 and about 6 percent less net thrust horsepower at about 2 percent lower net thrust specific fuel consumption than the compound power plant using engine 2 at the values of p_e/p_m for maximum power.

A breakdown of the components that make up the net thrust horsepower is shown in the following table for a value of p_e/p_m of 1.0:

Engine	Engine power (hp)	Turbine power (hp)	Auxiliary super-charger power (hp)	Jet power (hp)	Cooling-air drag (hp)	Net thrust power (hp)	Net thrust specific fuel consumption (lb/hp-hr)
			Cruise power				
1	1306	578	143	32	51	1442	0.388
2	1095	595	143	33	-22	1350	.411
3	1100	545	135	30	-7	1303	.403
			Rated power				
1	1819	954	224	55	206	1984	0.537
2	1638	1034	230	60	-12	2113	.507
3	1700	915	218	53	26	2035	.499

The table shows that changing the 62°-valve-overlap cams of engine 2 to 40° (engine 3) increased the engine power and cooling-air drag power and decreased the turbine power, auxiliary supercharger power and jet power for both cruise- and rated-power conditions. The decrease in turbine power was the greatest component power change and resulted in the lower net thrust power of compound engine 3 as compared with that of compound engine 2. The net thrust power of compound engine 1 was greater than that of either engine 2 or 3 at cruise condition because of the higher engine power. At the rated-power condition, the thrust power of compound engine 1 was lower than that of either engine 2 or 3 in spite of the higher engine power because of the greater cooling-air drag.

SUMMARY OF RESULTS

A comparison of performance and calculated data obtained from three 18-cylinder, air-cooled, radial engines – engine 1 (40° valve overlap), engine 2 (62° valve overlap with increased cooling-fin area) and engine 3 (engine 2 modified with 40°-valve-overlap cams), showed that:

1. Engine 3 provided slightly less brake horsepower than engine 1 over the entire range of the ratio of engine exhaust to inlet-manifold pressure p_e/p_m. At low values of p_e/p_m, engine 3 provided less brake horsepower than engine 2; however, at higher values of p_e/p_m, engine 3 provided more power than engine 2.

2. Charge-air flow, volumetric efficiency, and the ratio of indicated mean effective pressure to inlet-manifold pressure ϕ, showed the same trend with p_e/p_m as brake horsepower.

3. At cruise power, the compound power plant using engine 3 gave about 9 percent less thrust horsepower at about 4 percent higher net thrust specific fuel consumption than that using engine 1 and about 6 percent less net thrust horsepower at about 4 percent lower net thrust specific fuel consumption than the compound power plant using engine 2 at the values of p_e/p_m for maximum power.

4. At rated power, the compound power plant using engine 3 gave about 2 percent more net thrust horsepower at about 5 percent lower net thrust specific fuel consumption than that using engine 1 and about 6 percent less net thrust horsepower at about 2 percent lower net thrust specific fuel consumption than the compound power plant using engine 2 at the values of p_e/p_m for maximum power.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, January 20, 1948.

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1. Boman, David S., Nagey, Tibor F., and Doyle, Ronald B.: Effect of Exhaust Pressure on the Performance of an 18-Cylinder Air-Cooled Radial Engine with a Valve Overlap of 40°. NACA TN No. 1220, 1947.

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3. Hannum, Richard W., and Zimmerman, Richard H.: Calculations of Economy of 18-Cylinder Radial Aircraft Engine with Exhaust-Gas Turbine Geared to the Crankshaft. NACA Rep. No. 822, 1945.

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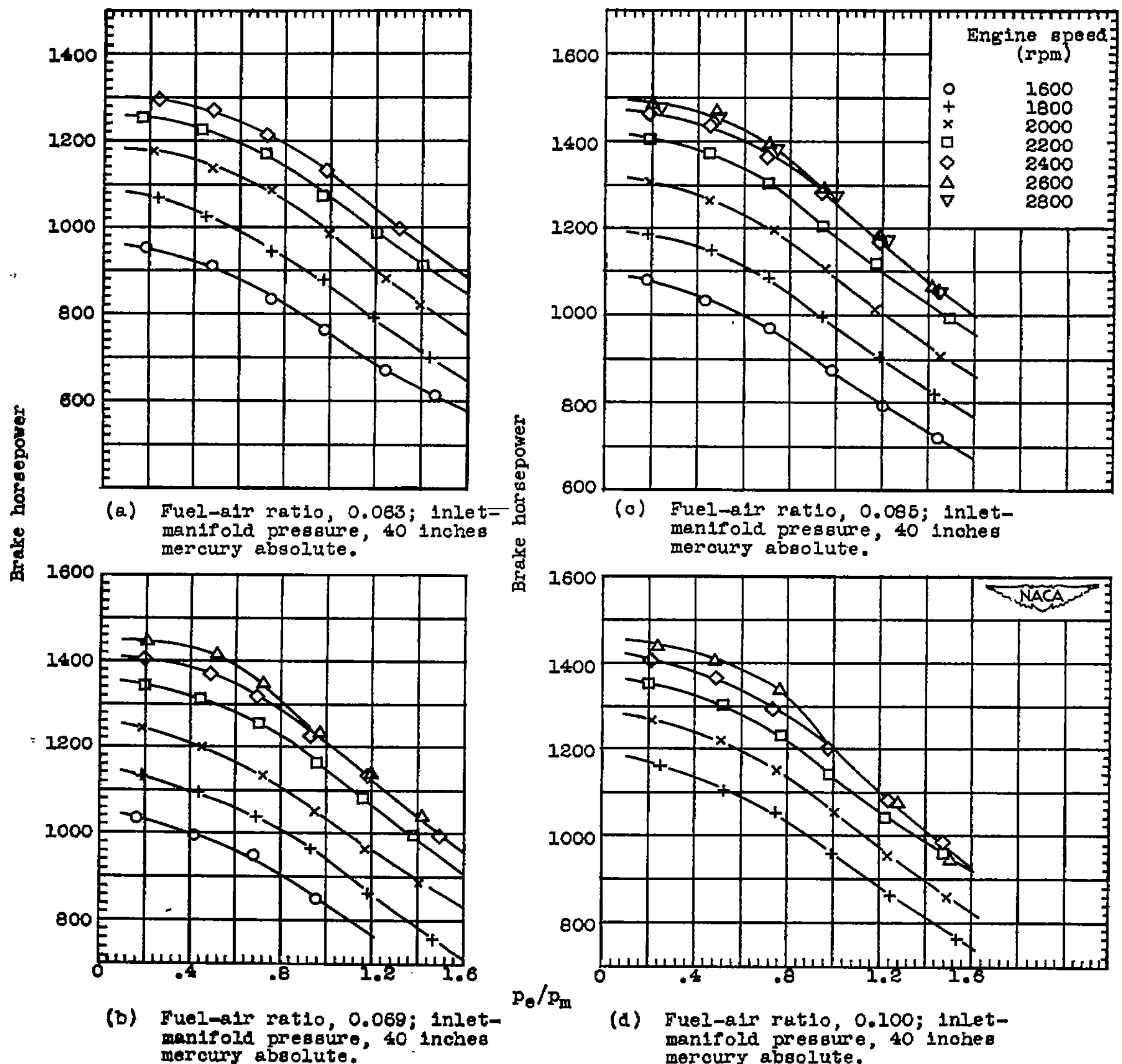
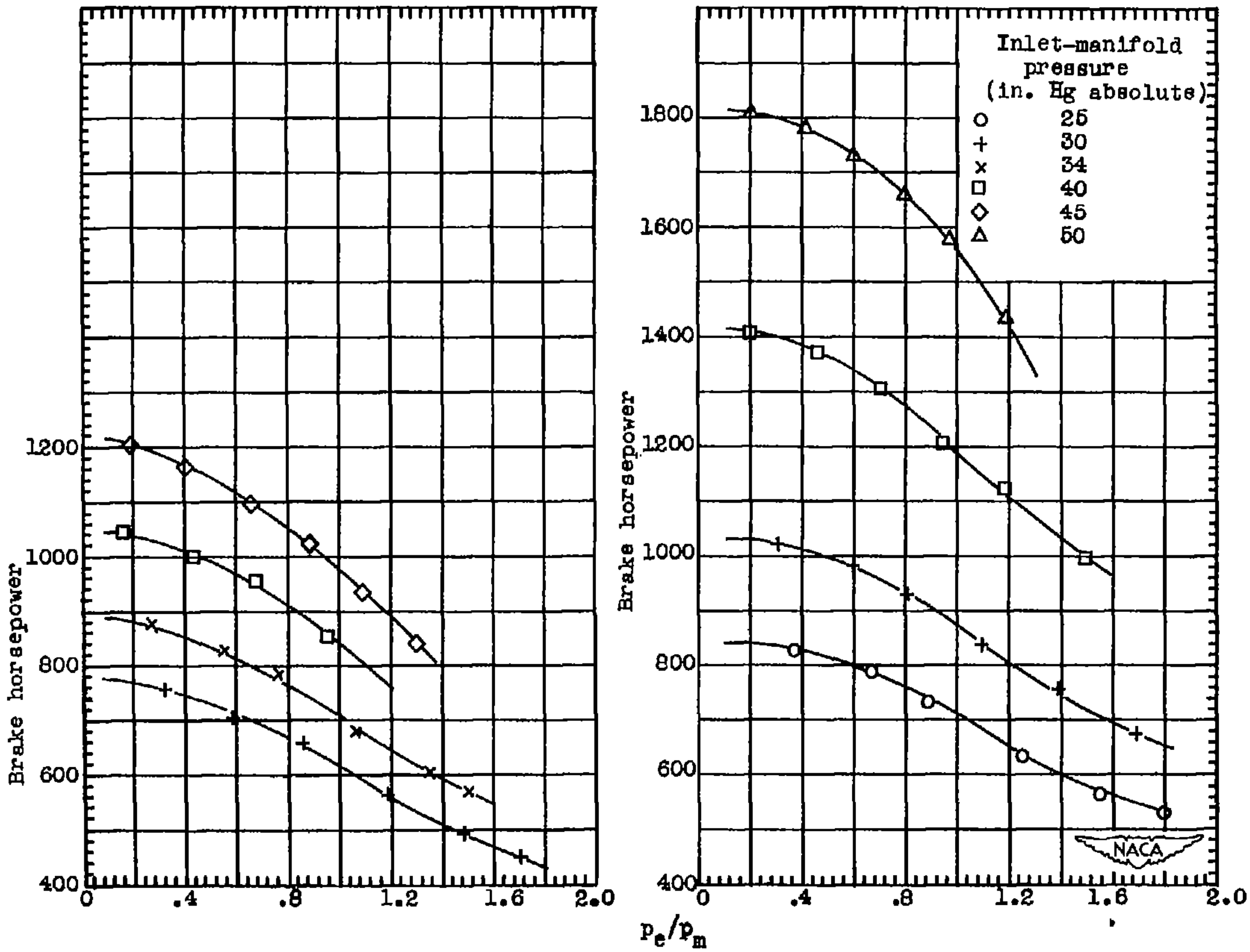


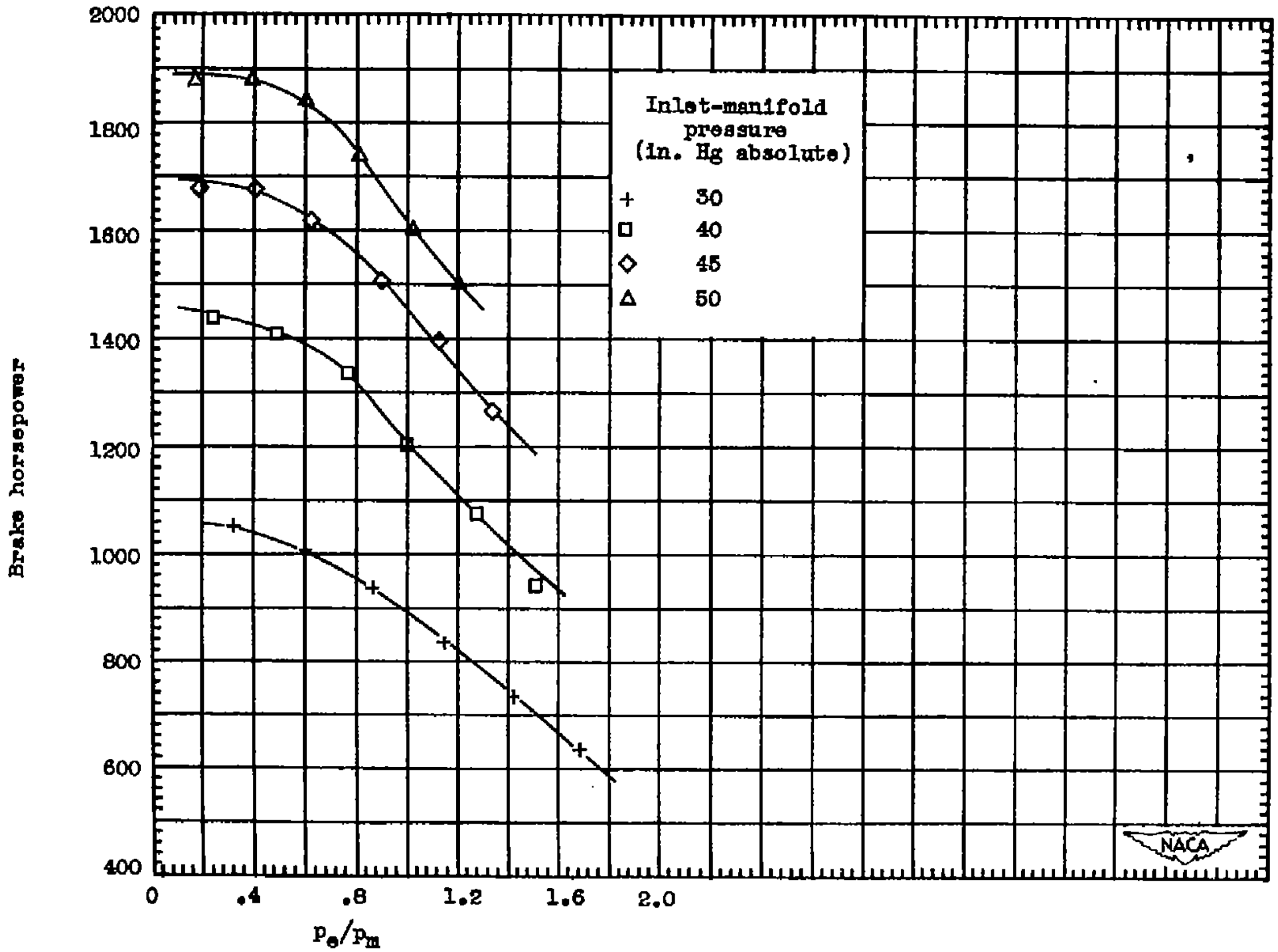
Figure 1. - Variation of brake horsepower with p_e/p_m. Brake horsepower corrected to constant carburetor-air temperature of 550° R. Engine 3, 40° valve overlap.



(e) Engine speed, 1600 rpm; fuel-air ratio, 0.069.

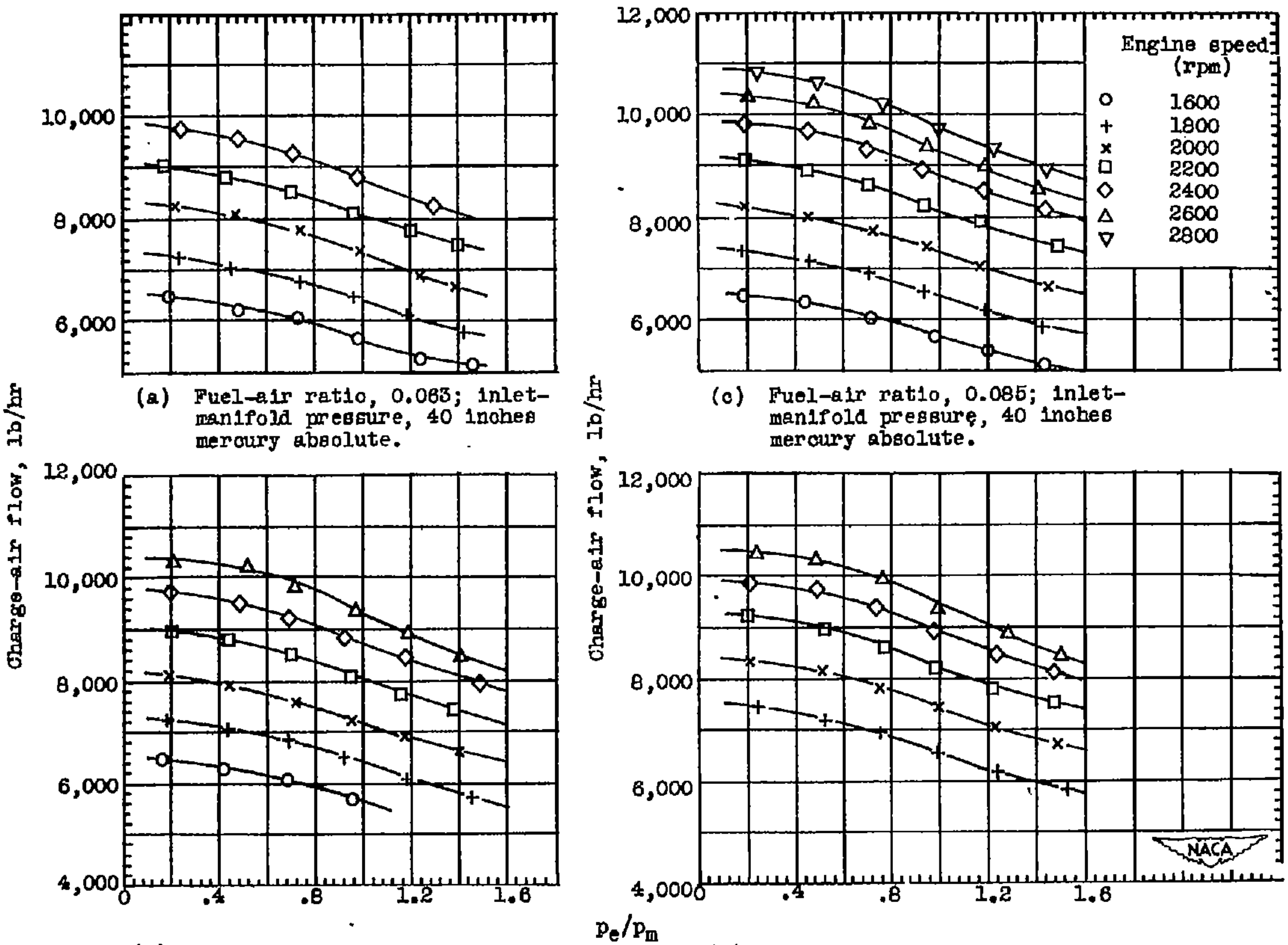
(f) Engine speed, 2200 rpm; fuel-air ratio, 0.085.

Figure 1. - Continued. Variation of brake horsepower with p_e/p_m. Brake horsepower corrected to constant carburetor-air temperature of 550° R. Engine 3, 40° valve overlap.



(g) Engine speed, 2600 rpm; fuel-air ratio, 0.100.

Figure 1. - Concluded. Variation of brake horsepower with p_e/p_m. Brake horsepower corrected to constant carburetor-air temperature of 550° R. Engine 3, 40° valve overlap.



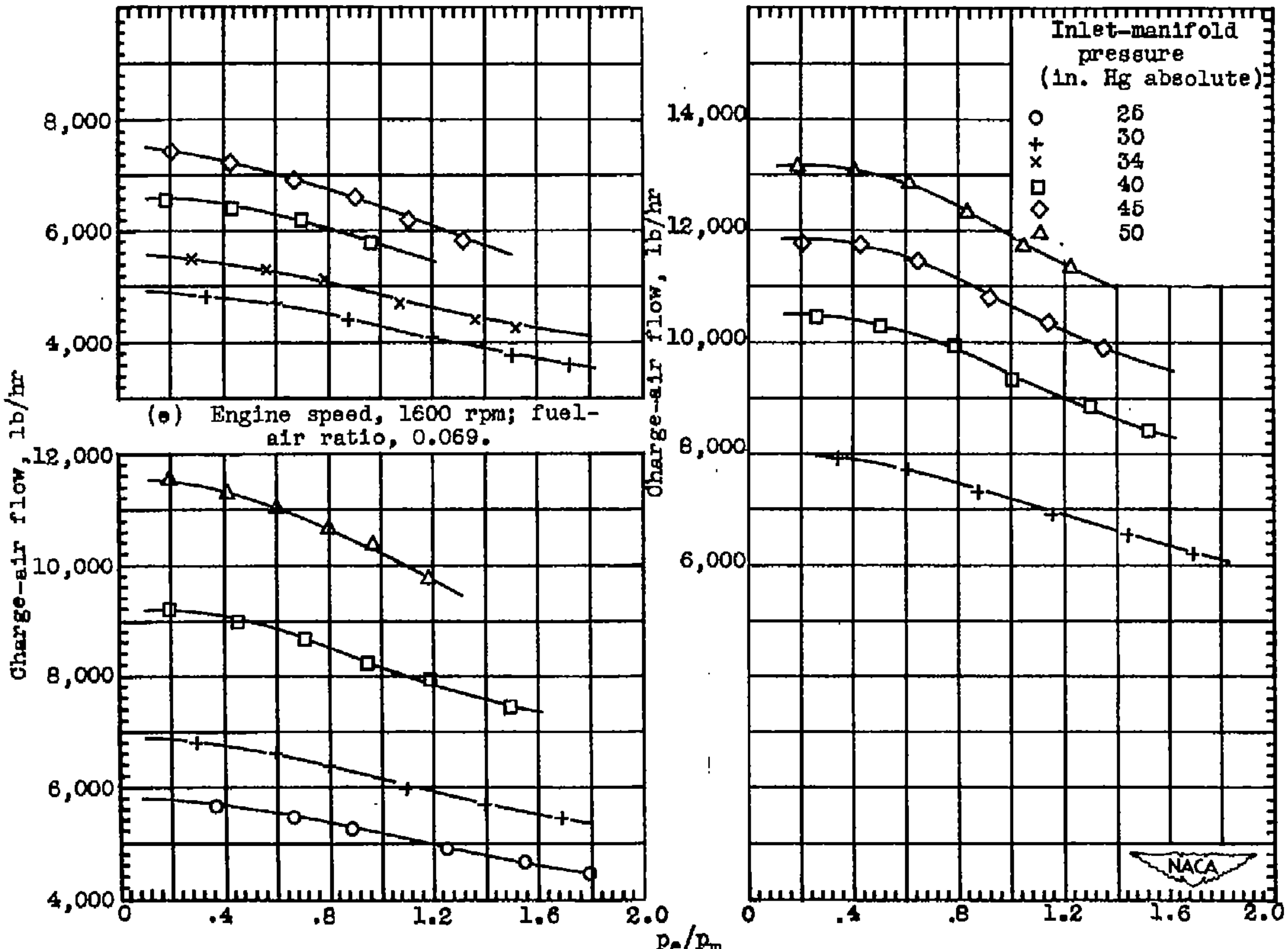
(a) Fuel-air ratio, 0.063; inlet-manifold pressure, 40 inches mercury absolute.

(b) Fuel-air ratio, 0.069; inlet-manifold pressure, 40 inches mercury absolute.

(c) Fuel-air ratio, 0.085; inlet-manifold pressure, 40 inches mercury absolute.

(d) Fuel-air ratio, 0.100; inlet-manifold pressure, 40 inches mercury absolute.

Figure 2. - Variation of charge-air flow with p_e/p_m. Charge-air flow corrected to constant carburetor-air temperature of 550° R. Engine 3, 40° valve overlap.



(e) Engine speed, 1600 rpm; fuel-air ratio, 0.069.

(f) Engine speed, 2200 rpm; fuel-air ratio, 0.085.

(g) Engine speed, 2600 rpm; fuel-air ratio, 0.100.

Figure 2. - Concluded. Variation of charge-air flow with p_e/p_m. Charge-air flow corrected to constant carburetor-air temperature of 550° R. Engine 3, 40° valve overlap.

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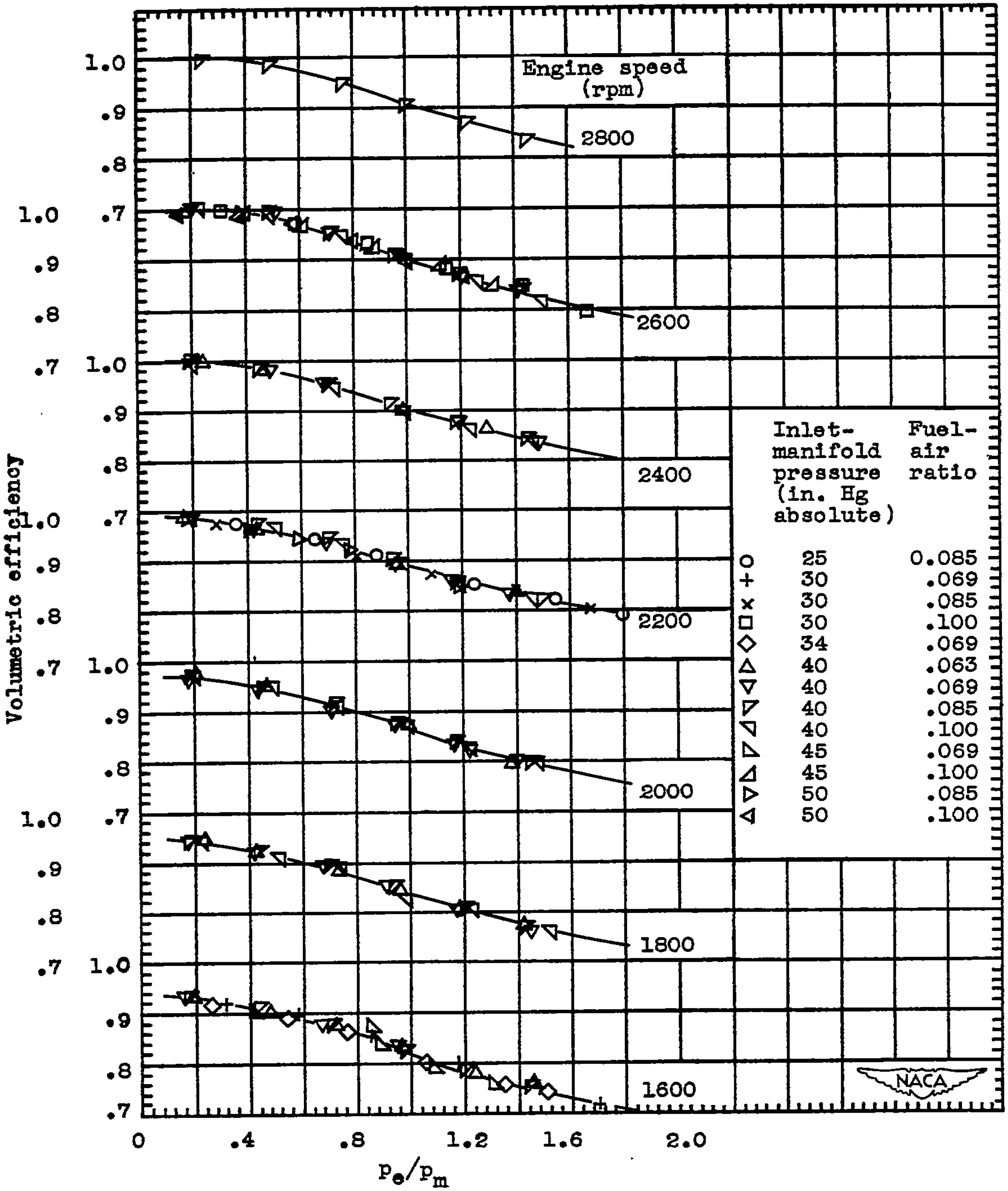
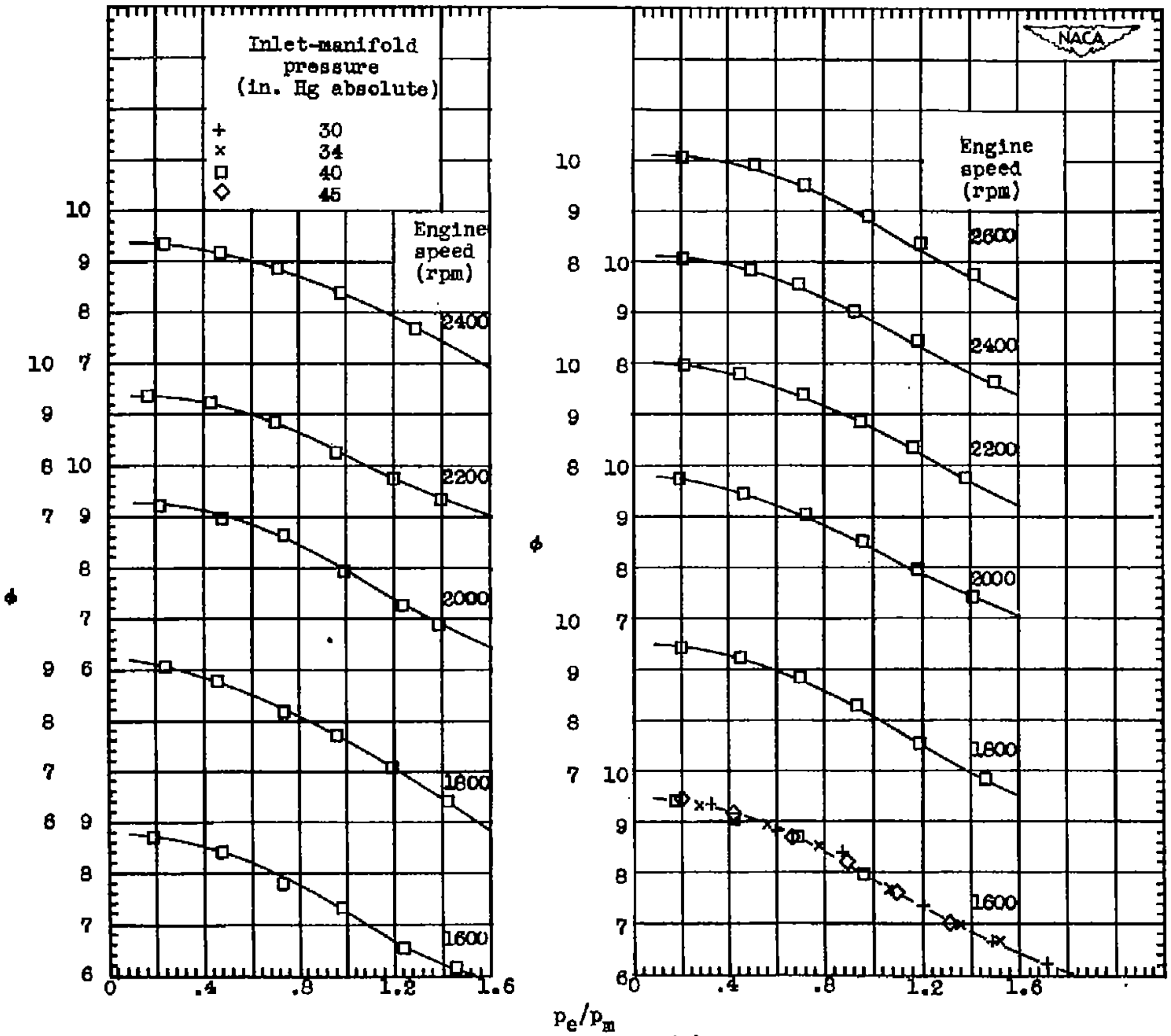


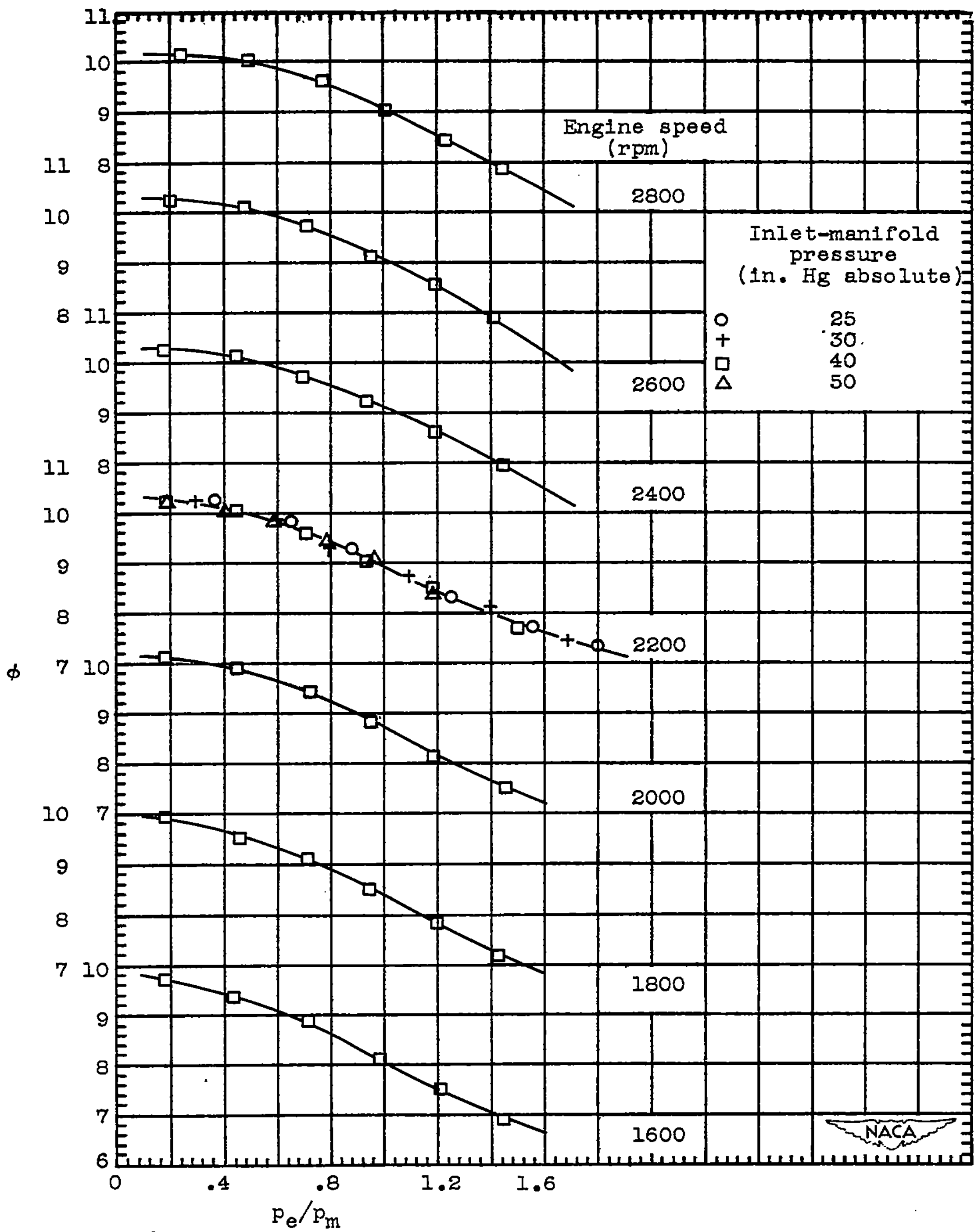
Figure 3. - Variation of volumetric efficiency with p_e/p_m. Engine 3, 40° valve overlap.



(a) Fuel-air ratio, 0.063.

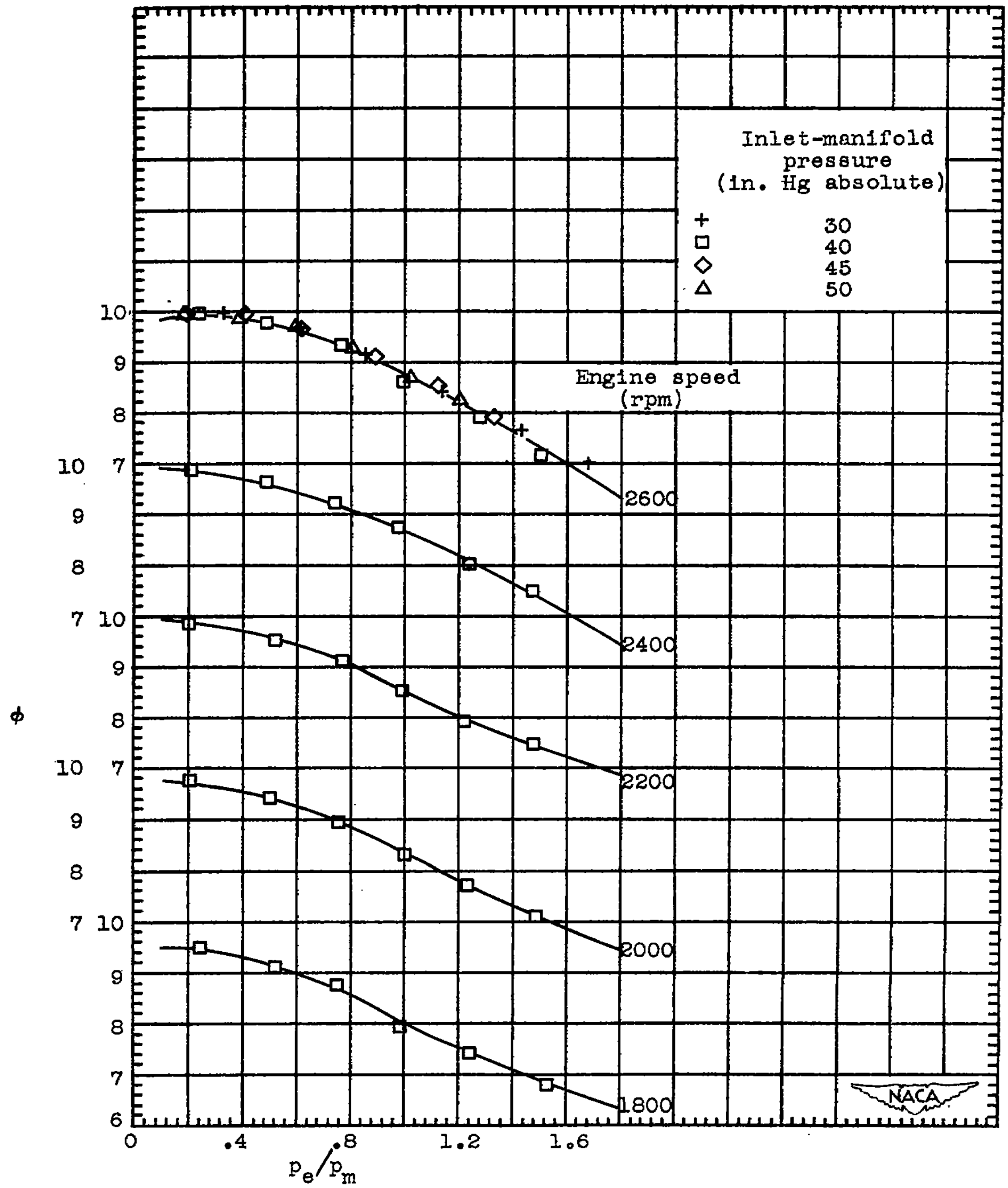
(b) Fuel-air ratio, 0.069.

Figure 4. - Variation of ϕ with p_e/p_m. Values of ϕ corrected to constant inlet-manifold temperature of 660° R. Engine 3, 40° valve overlap.



(c) Fuel-air ratio, 0.085.

Figure 4. - Continued. Variation of ϕ with p_e/p_m. Values of ϕ corrected to constant inlet-manifold temperature of 660° R. Engine 3, 40° valve overlap.



(d) Fuel-air ratio, 0.100.

Figure 4. - Concluded. Variation of ϕ with p_e/p_m. Values of ϕ corrected to constant inlet-manifold temperature of 660° R. Engine 3, 40° valve overlap.

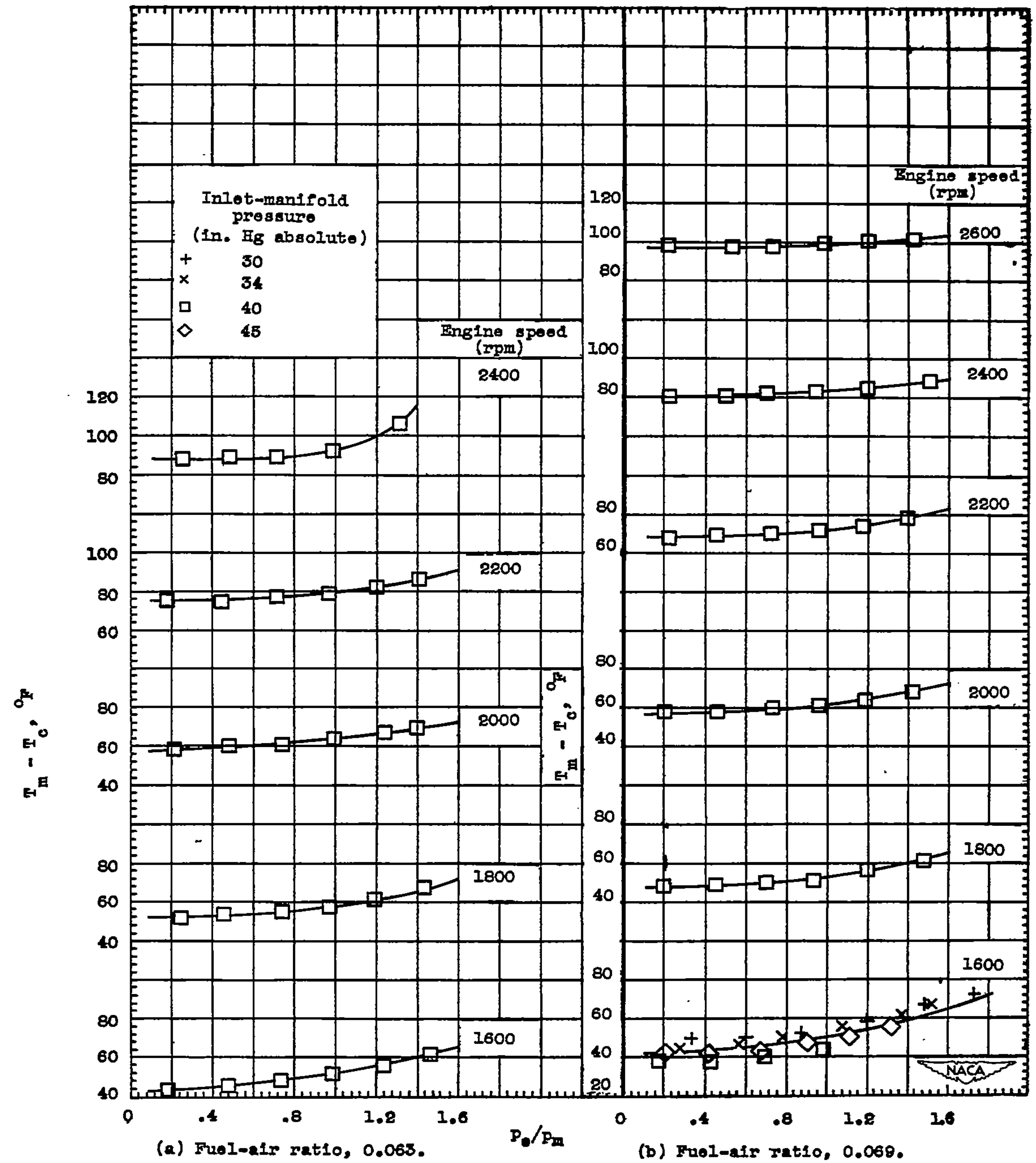


Figure 5. - Variation of mixture temperature minus carburetor-air temperature $T_m - T_c$ with p_e/p_m. Engine 3, 40° valve overlap.

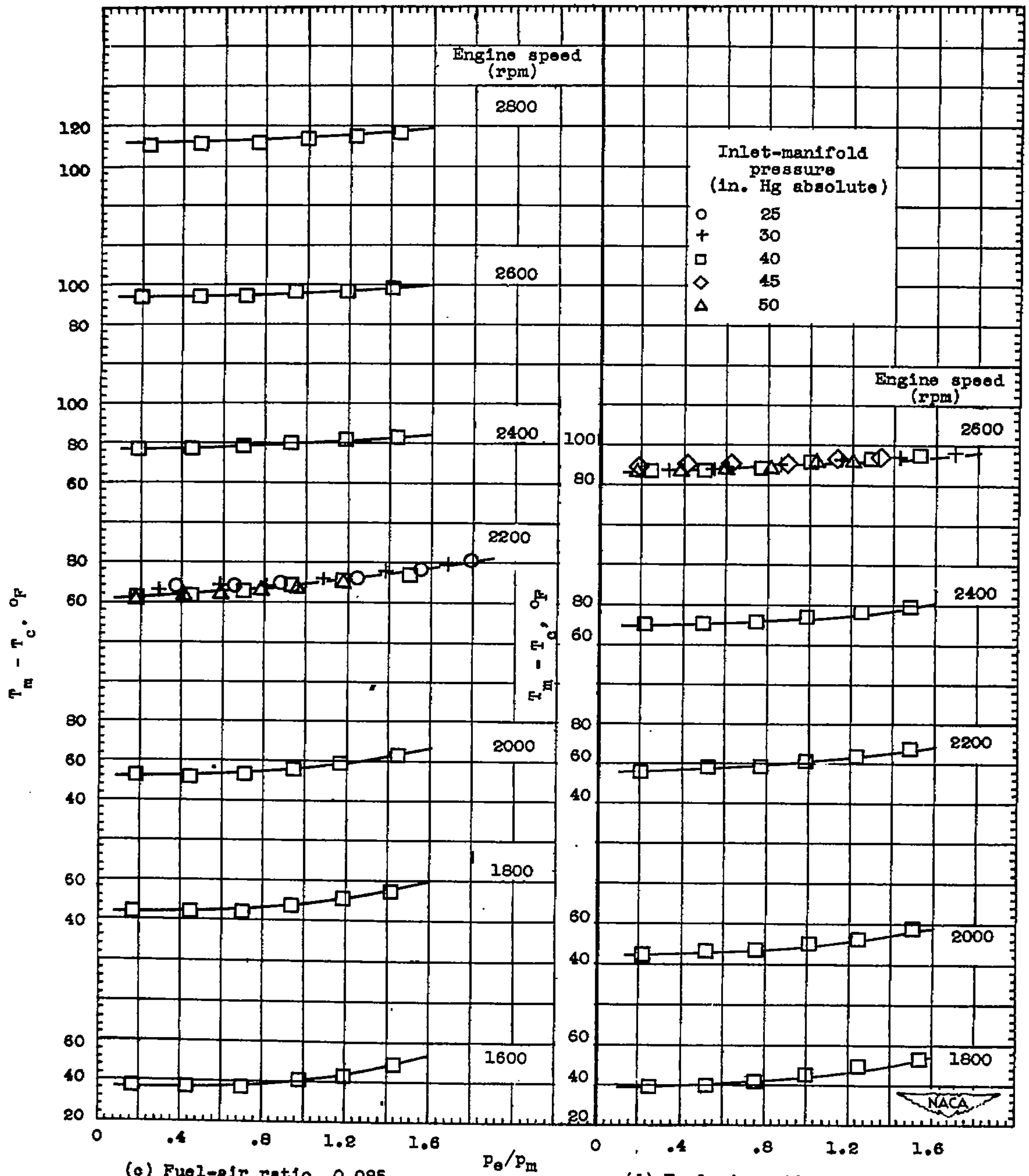
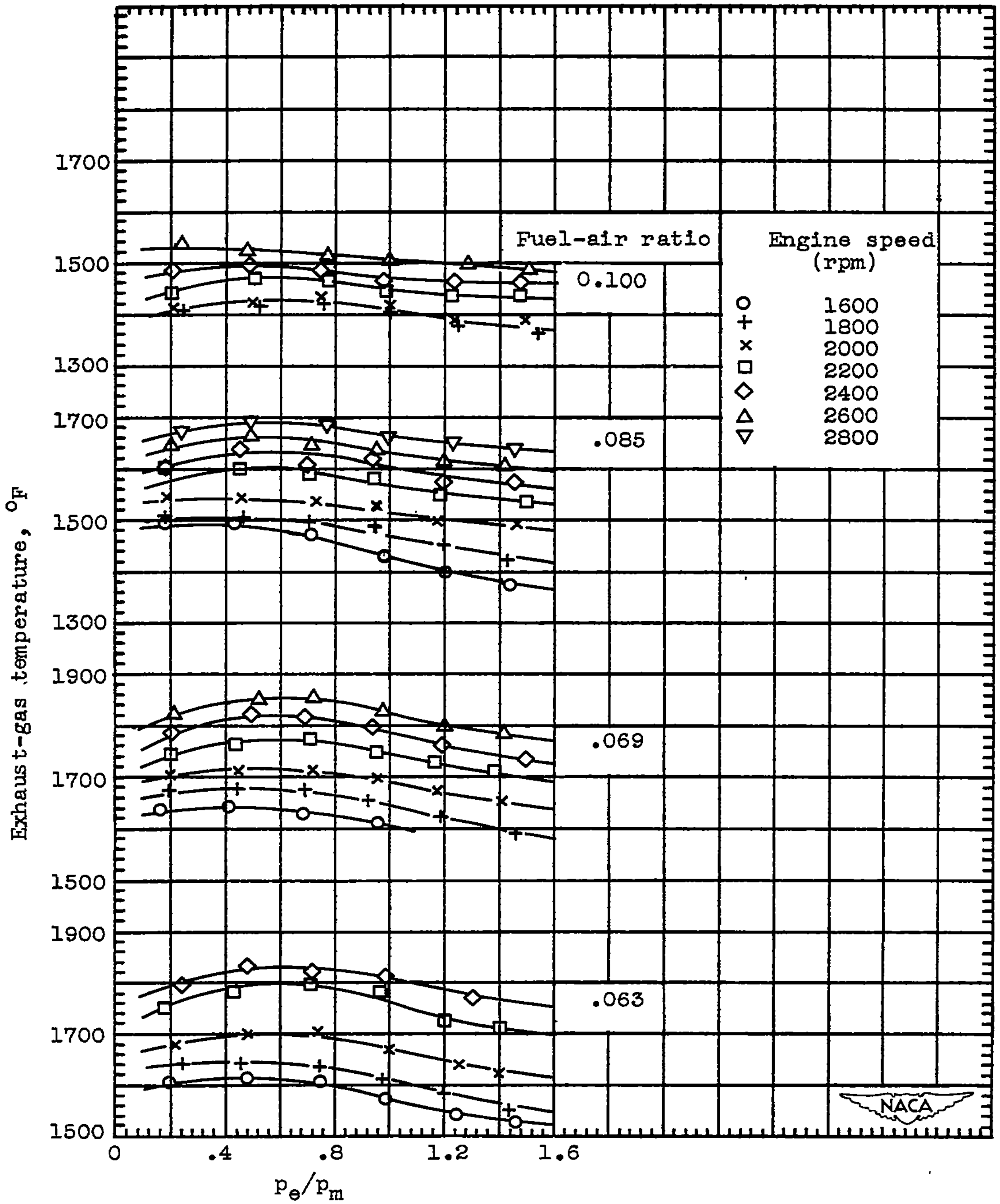
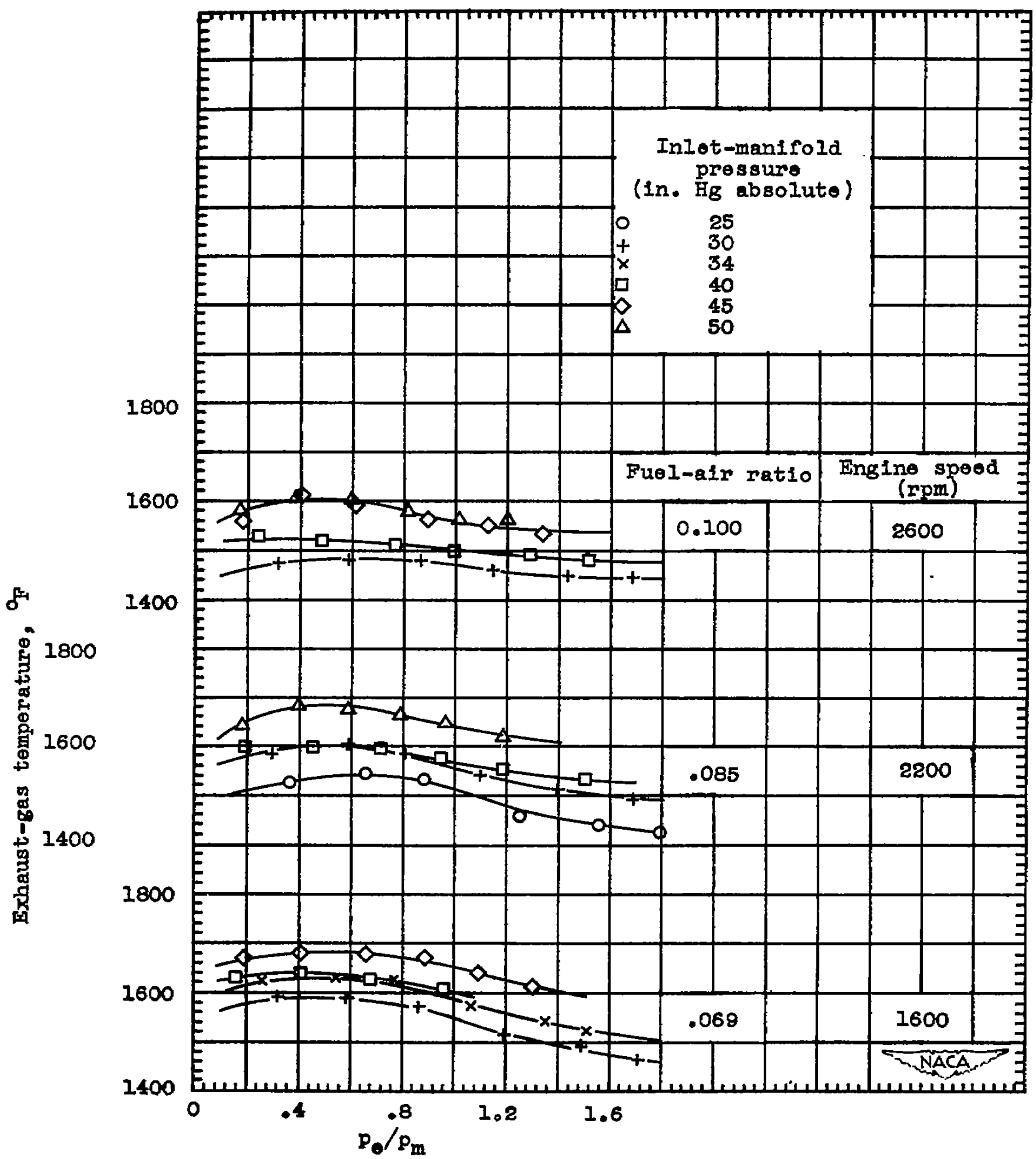


Figure 5. - Concluded. Variation of mixture temperature minus carburetor-air temperature $T_m - T_c$ with p_e/p_m. Engine 3, 40° valve overlap.



(a) Inlet-manifold pressure, 40 inches mercury absolute.

Figure 6. - Variation of exhaust-gas temperature with p_e/p_m. Engine 3, 40° valve overlap.



(b) Variable inlet-manifold pressure.

Figure 6. - Concluded. Variation of exhaust-gas temperature with p_e/p_m. Engine 3, 40° valve overlap.

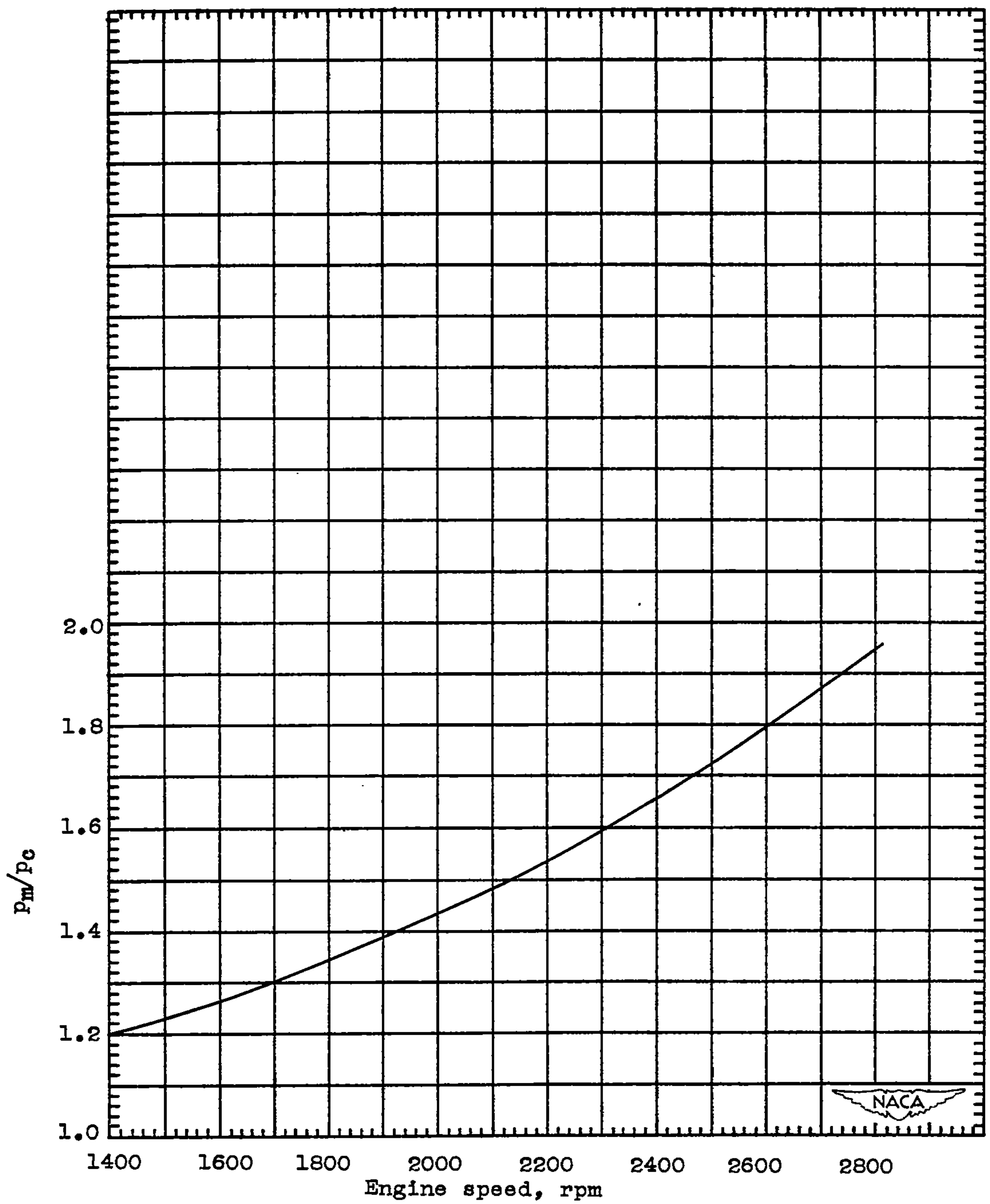


Figure 7. - Variation of ratio of inlet-manifold pressure to full-open throttle carburetor-inlet pressure p_m/p_c with engine speed. Carburetor-air temperature, 550° R.

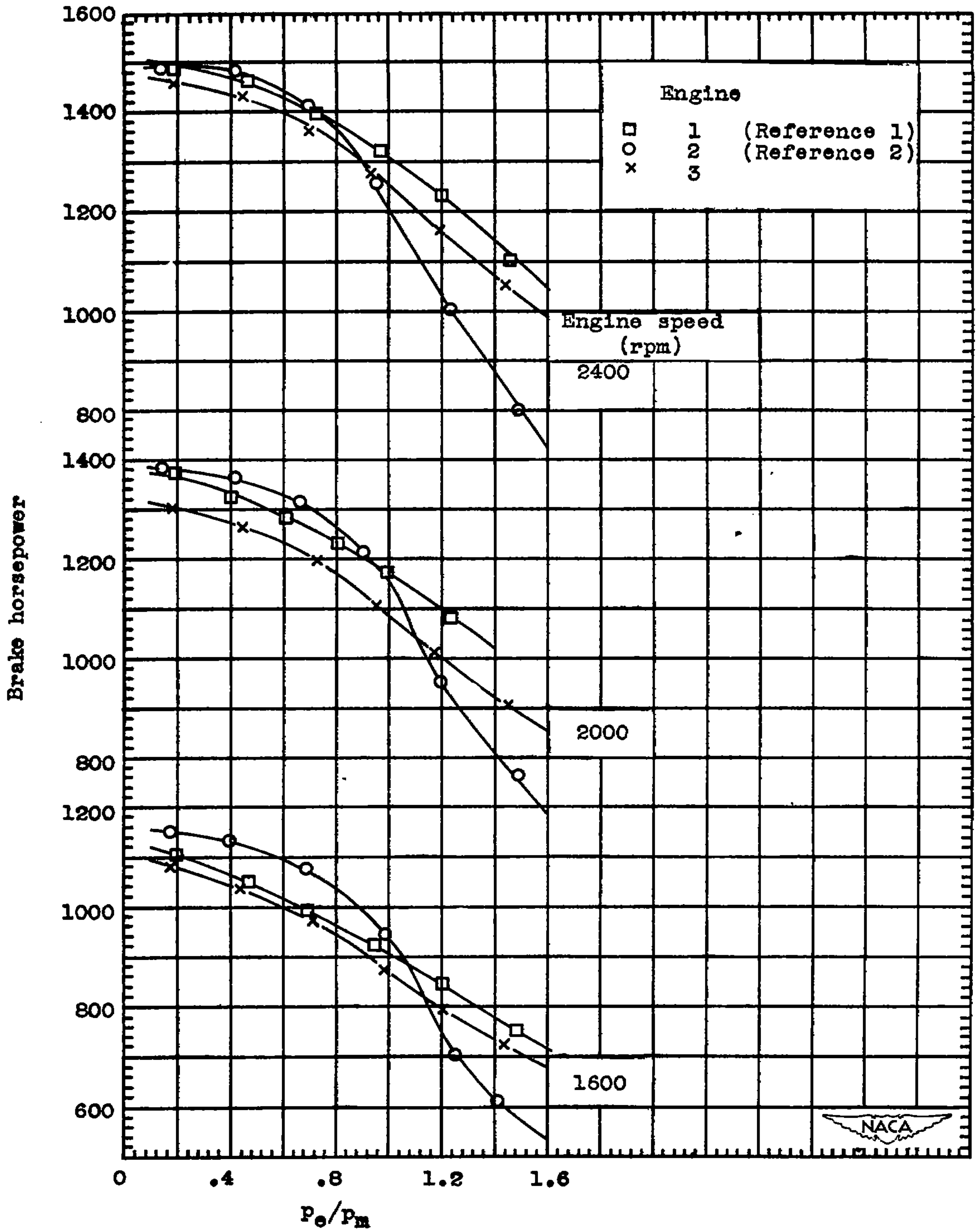


Figure 8. - Curves of brake horsepower from figure 1 plotted with curves of brake horsepower from references 1 and 2. Inlet-manifold pressure, 40 inches mercury absolute; fuel-air ratio, 0.085.

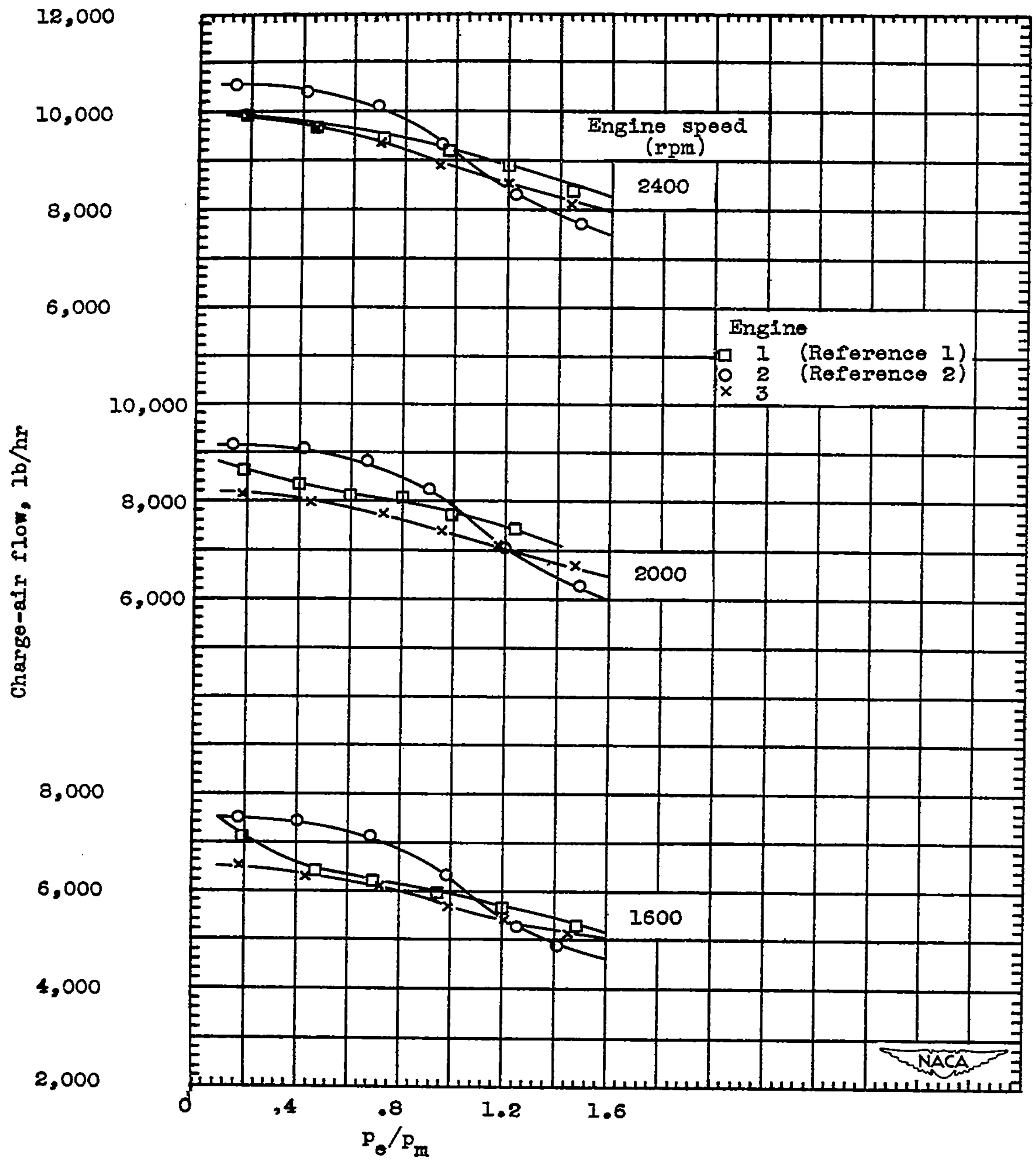


Figure 9. - Curves of charge-air flow from figure 2 plotted with curves of charge-air flow from references 1 and 2. Inlet-manifold pressure, 40 inches mercury absolute; fuel-air ratio, 0.085.

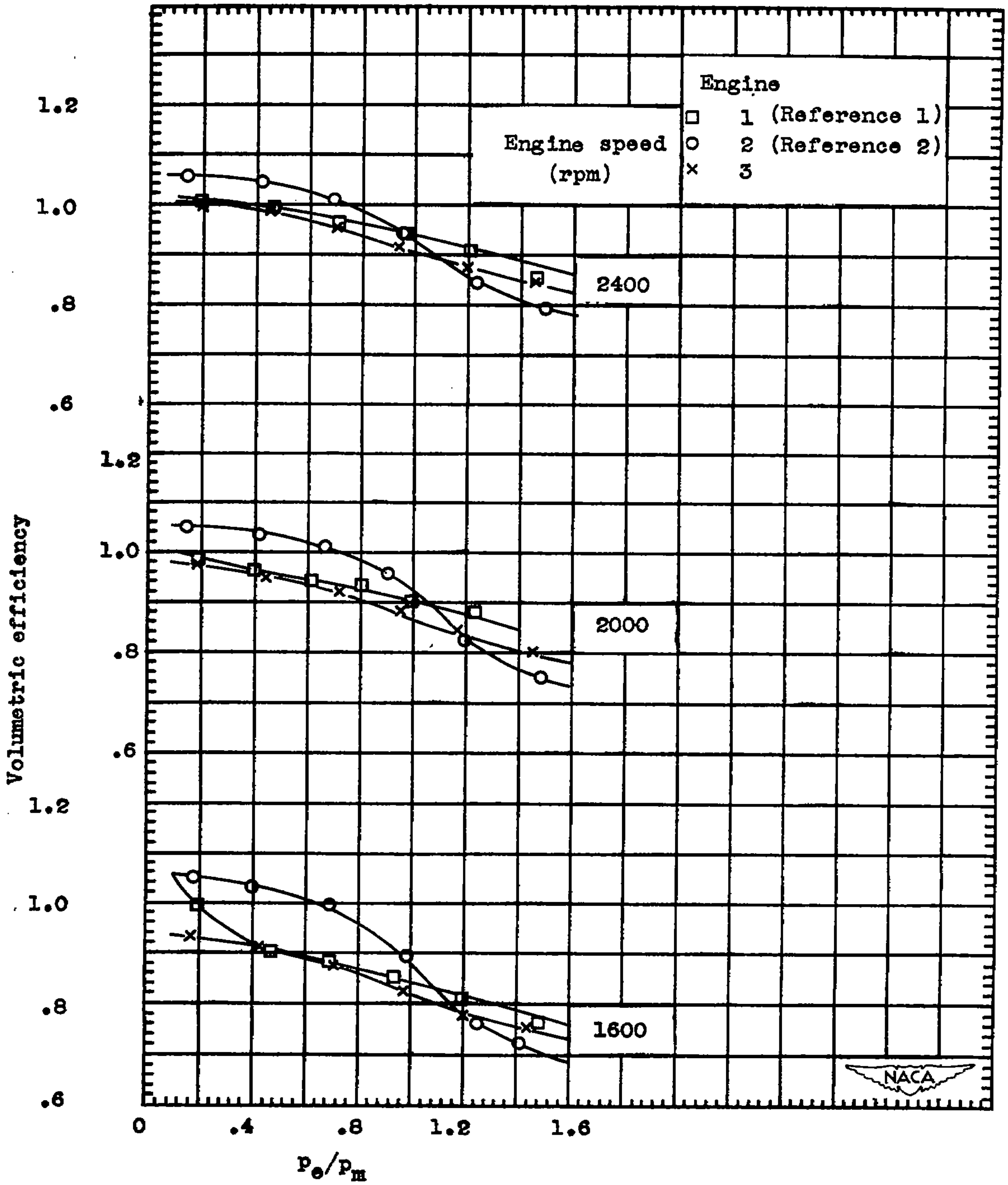


Figure 10. - Curves of volumetric efficiency from figure 3 plotted with curves of volumetric efficiency from references 1 and 2. Inlet-manifold pressure, 40 inches mercury absolute; fuel-air ratio, 0.085.

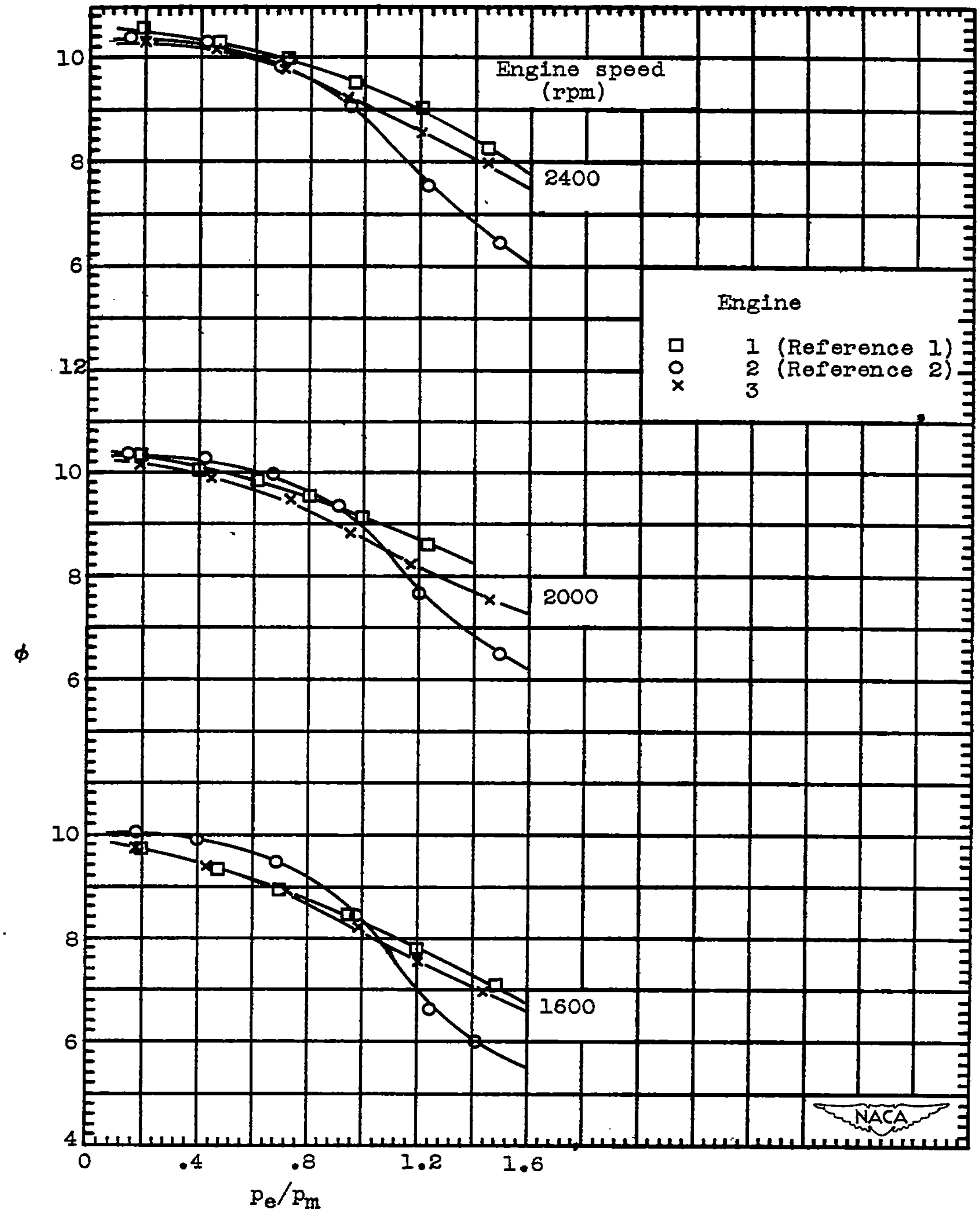


Figure 11. – Curves of ϕ from figure 4 plotted with curves of ϕ from references 1 and 2. Inlet-manifold pressure, 40 inches mercury absolute; fuel-air ratio, 0.085. Values of ϕ corrected to constant inlet-manifold temperature of 660° R.

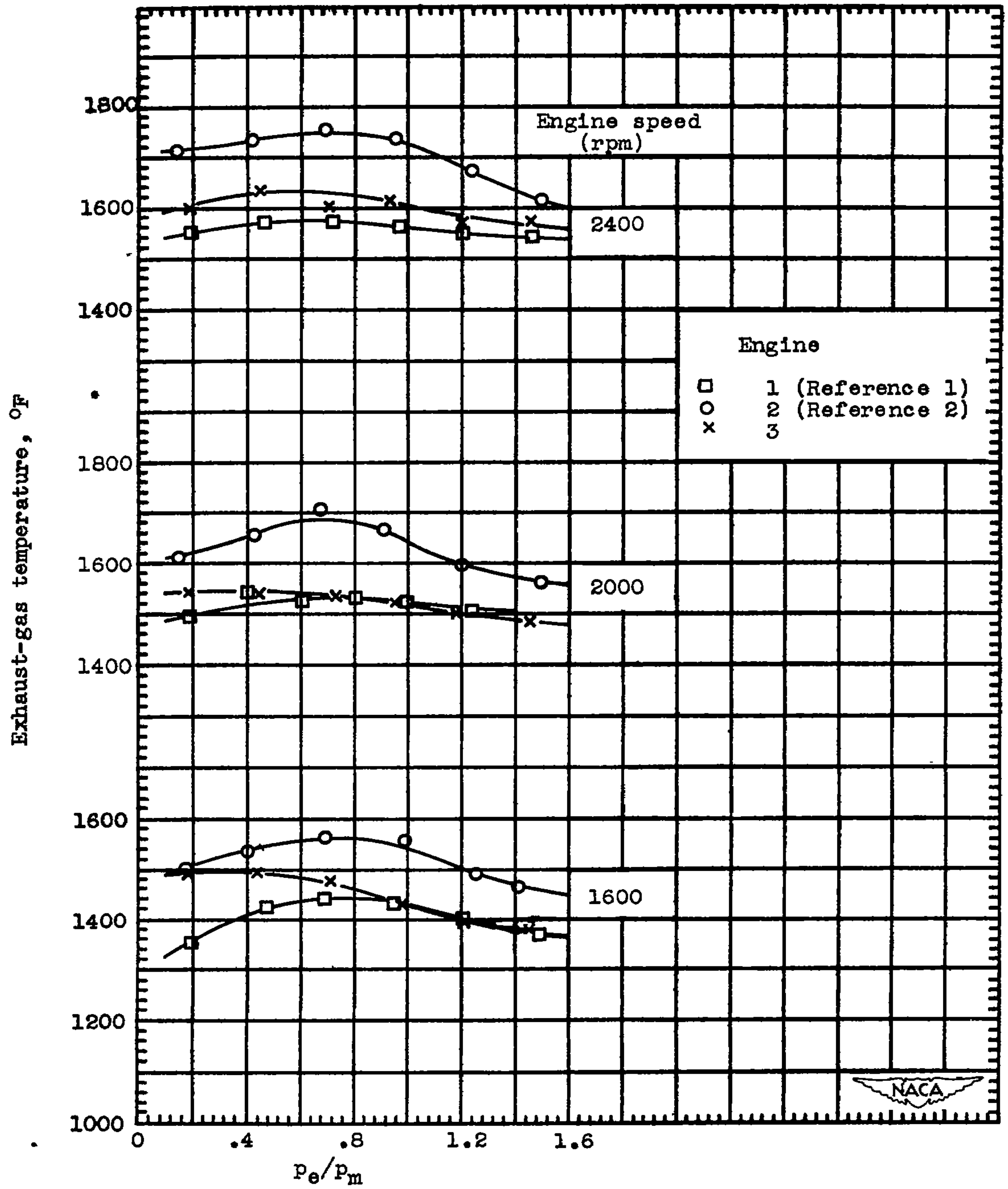
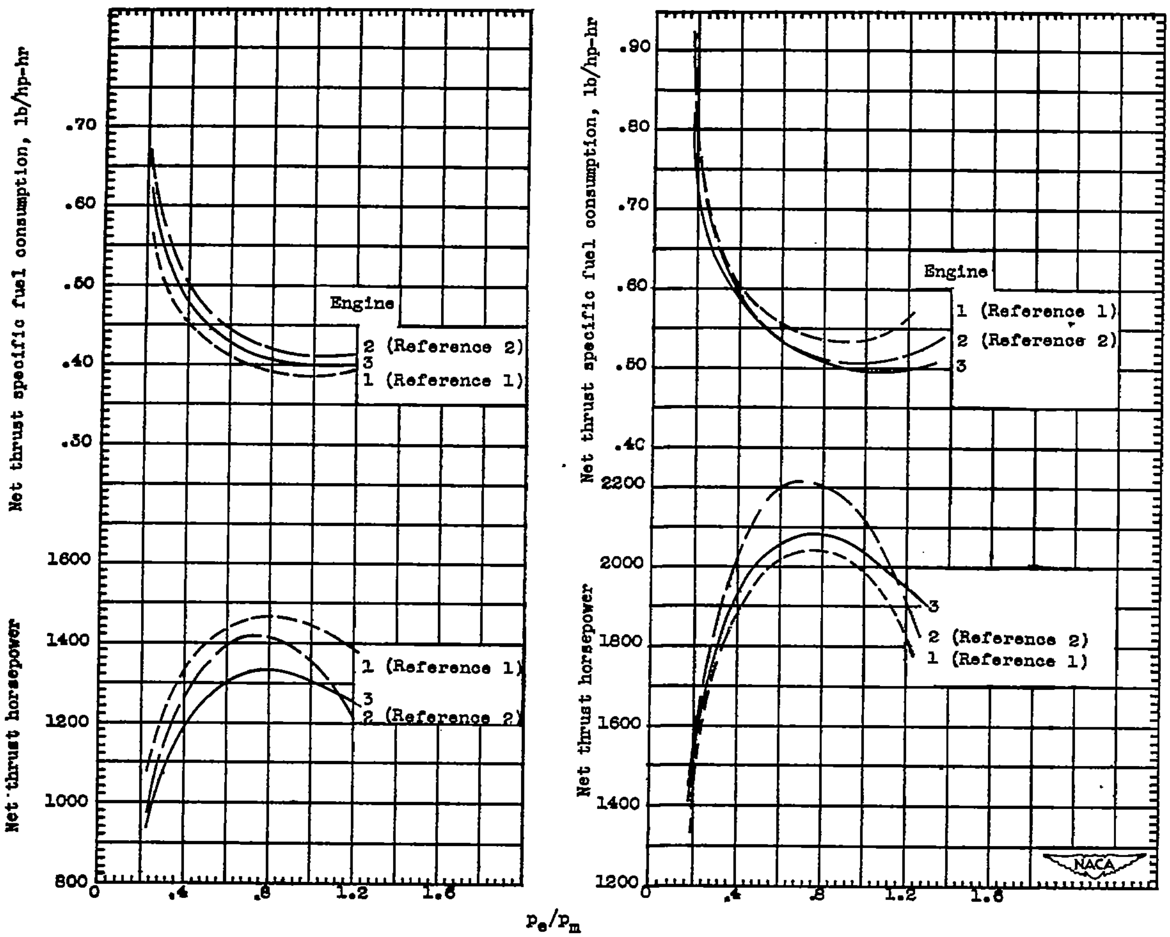


Figure 12. - Curves of exhaust-gas temperature from figure 6 plotted with curves of exhaust-gas temperature from references 1 and 2. Inlet-manifold pressure, 40 inches mercury absolute; fuel-air ratio, 0.085.



(a) Engine speed, 2200 rpm; fuel-air ratio, 0.063; inlet-manifold pressure, 40 inches mercury absolute.

(b) Engine speed, 2600 rpm; fuel-air ratio, 0.085; inlet-manifold pressure, 50 inches mercury absolute.

Figure 13. - Variation of compound-power-plant performance with p_e/p_m for compound power plants using three different engines. Flight velocity, 400 miles per hour; altitude, 30,000 feet.